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bornites is doubtless due to admixed chalcocite just as the iron content of chalcocite is usually due to admixed bornite.

There are four possible explanations of the variability in chemical composition of bornite, viz: (1) Mechanical mixture, (2) isomorphous mixture, (3) morphotropic series (Kraus and Goldsberry), (4) solid solution.

1. While it is certain that mechanical mixtures explain part of the variability, some other factor is involved, as we know from the analytical results of Kraus and Goldsberry.

2. The isomorphism of bornite and chalcocite does not seem at all probable for there is not much similarity in chemical composition; moreover, one is isometric, the other orthorhombic.

3. The term morphotropy was introduced by Groth⁵ to indicate the change in crystalline form brought about by substituting in a chemical compound an atom or group of atoms for a similar atom or group. The best examples of morphotropy are furnished by organic compounds. The only clear case of morphotropy (in its original restricted sense as distinct from isomorphism) among minerals is the humite group. Kraus and Goldsberry contend that there are various bornites each with a definite formula. As far as known bornite is isometric and, if so, it is difficult to conceive of any crystallographic change that can be brought about by the addition of the Cu_3S molecule. Complex formulæ like $\text{Cu}_{34}\text{Fe}_2\text{S}_{20}$, $\text{Cu}_{40}\text{Fe}_2\text{S}_{23}$ and $\text{Cu}_{76}\text{Fe}_2\text{S}_{41}$ are very improbable and it is probably a coincidence that the percentage compositions of the crystallized bornite from Bristol are so close to the theoretical values of $\text{Cu}_{10}\text{Fe}_2\text{S}_8$ and $\text{Cu}_{12}\text{Fe}_2\text{S}_9$.

4. In order to explain the variable chemical composition of bornite, the hypothesis of solid solution is advanced by the writer. As the lower limit of bornite seems to be Cu_3FeS_3 , the variation in composition can be explained by assuming that *bornite is a solid solution of Cu_3S in Cu_3FeS_3* which may be indicated thus: $\text{Cu}_3\text{FeS}_3(\text{Cu}_3\text{S})_x$. This makes an indefinite upper limit for the copper content. There is proof that it is as high as $\text{Cu}_{12}\text{Fe}_2\text{S}_9$, and it

⁵ *Pogg. Ann.*, 141, 31, 1870.

probably goes still higher. The composition of bornites listed on page 547 of Kraus and Goldsberry's paper is as easily explained by the solid solution hypothesis as by any other and from a chemical standpoint it seems far more reasonable. The solid solution hypothesis also helps to explain the fact that chalcocite rarely occurs as an original hypogene⁶ mineral for it seems probable that cuprous sulfoferrite (Cu_3FeS_3) can take up or dissolve appreciable amounts of cuprous sulfid, and hence chalcocite is not formed until a later stage when a change of conditions is brought about by decrease of temperature. It may also explain the readiness with which bornite alters to chalcocite. There is very little microscopic evidence to show that bornite and chalcocite are formed simultaneously except perhaps locally in the so-called intergrowths. The origin of these graphic intergrowths will be discussed by the writer in a forthcoming paper.

The long series of sulfo-salt minerals given by Kraus and Goldsberry fails to convince me of the general application of morphotropy in this group. Minerals represented by some of the formulæ in the series are doubtless examples of solid solutions, and some of these minerals are undoubtedly mechanical mixtures. Imagine what a bewildering lot of transparent minerals might have been recognized if mineralogists had had no microscopic check on their chemical work. A revision of the opaque sulfo-salt minerals seems necessary. In such work the metallographic microscope will be of great assistance.

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STUDIES IN THE MEASUREMENT OF THE ELECTRICAL CONDUCTIVITY OF SOLUTIONS¹

It is a striking fact that very few investigators of conductivity have striven to make the measurements with an accuracy approach-

¹ This work was made possible by a grant from the Carnegie Institution of Washington to Professor S. F. Acree. New Orleans meeting of the American Chemical Society, April, 1915.

⁶ This useful term is used by Ransome for minerals or ores formed by ascending solutions.

ing 0.01 per cent., and the writer has, with suggestions from Professor S. F. Acree, attempted to improve upon the technique employed by studying the conductivity cells, the baths, temperature regulation, the bridge and resistances, the methods of making and handling the solutions, and the so-called electrode and polarization phenomena. This improvement is now necessary in order to allow the writer to use the conductivity method for the determination of ionizations and reaction velocities in dilute solutions. He is indebted to Dr. Curtis² and Dr. Wenner, of the National Bureau of Standards, for much valuable advice, and the fine work of Washburn³ and Bell shows what great improvements can be made in this line.

The writer has used the excellent equipment of the Bureau of Standards and some fine apparatus loaned us by Leeds and Northrup in making a fundamental study of a large number of factors, some of which have already been investigated in conductivity work by physical chemists. As a result of this work he has already greatly improved the methods and has studied: (1) the current from (a) induction coils, (b) a Holzer-Cabot wireless generator, (c) a General Electric Company large generator, (d) a Siemens-Halske generator for conductivity work, and (e) a Vreeland oscillator furnished by Leeds, Northrup & Co., which we have found to be the best source of current yet tried, as it gives a pure sine wave of uniform frequency which can be varied very widely; (2) the voltage, which when varied from 0.25 to 8 volts, has shown no influence on the resistance of the solutions measured so far *in very clean cells*, but is very important in cells not entirely clean; (3) the size and shape of the electrodes, which have a very large influence on the change of resistance and capacity of the cell with change in frequency; (4) the material used in making the electrodes (Pt, Au, Ag, Cu, Zn, etc.), which is very important; (5) the state of aggregation of the surface of the

electrodes, as in plain, gray and platinized electrodes, which has a very great influence on the capacity of the cell and change of resistance with change in frequency; (6) the frequency of the alternating current, which when varied may change the resistance of some solutions in some cells as much as 3 per cent.; (7) the high capacity of the cell as a condenser, which is very important in decreasing the change of resistance with change in frequency and in obtaining a perfect minimum in the telephone; (8) the valence and velocities of the different ions; (9) the influence of the concentration and the character of the electrolyte and the solvent on the change of resistance with change in frequency; (10) the proper use of a condenser or inductance in balancing the capacity of the cell, and its influence on the resistance and minimum in the telephone; (11) the construction of the cell in such a way that no errors from evaporation and concentration can be produced; (12) the use of a tuned telephone attached to a stethoscope or of double wireless telephones; (13) the construction of a Wheatstone bridge with Curtis resistances free from inductance and capacity, kept automatically at constant temperature, and arranged so that every resistance can be checked against the others and against standard enclosed resistance; (14) the development of especially good constant temperature baths for such work; (15) the use of weight methods and special apparatus for making, keeping and transferring solutions; (16) a number of points connected with the proper use of all of the apparatus, especially the electrical equipment, to prevent errors arising from induction, capacity, skin effects, electrical leaks and other factors; (17) our criterion of excellent cells, namely that each one must be independent of the above sources of error and give readings constant to within 0.01 per cent., and especially that *whatever the solution used, the ratios of the resistances in any two such cells must be constant to within 0.01 per cent.* Only in this way can we be certain that the electrode effects have been practically eliminated and that we are measuring the true electrical resistance of the solution with great

² Curtis & Grover, Bureau of Standards Bulletin, Vol. 8, No. 3.

³ Jour. Am. Chem. Soc., 35, 177, 1913.

accuracy. By studying the electrode phenomena and other sources of error and correcting them we have now reached a precision of 0.001 per cent. and an accuracy of about 0.01 per cent. The details of all this work will appear shortly in another article.⁴

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PROCEEDINGS OF THE AMERICAN PHYSICAL SOCIETY

MINUTES OF THE SAN FRANCISCO MEETING

THE seventy-eighth meeting of the American Physical Society was held at San Francisco, August 2 to 7, 1915. It was a joint meeting with Section B of the American Association for the Advancement of Science. The programs of the meeting on Tuesday, Wednesday and Thursday were in charge of the committee of the Pacific Coast division of the American Association for the Advancement of Science, of which Professor Fernando Sanford was chairman, and those of Friday were in charge of the Physical Society, President Merritt presiding. The meeting on Wednesday was held at Stanford University, Palo Alto. All other sessions for the reading of physics papers were held at the physical laboratory of the University of California, Berkeley. General sessions of the American Association for the Advancement of Science were held in San Francisco.

The following papers were presented:

Tuesday Afternoon—Spectroscopy

(1) "A Summary of the Leading Features of Electric Furnace Spectra"; (2) "The Spectrum of the 'Tube-arc' and a Comparison with Line Dissymmetries in Spark Spectra," by Arthur S. King.

"Review of Laboratory Studies of the Zeeman Effect, at Mount Wilson Solar Observatory," by Harold D. Babcock.

"Pole Effect in the Arc and Its Relation to Other Investigations," by Charles E. St. John and Harold D. Babcock.

"The Efficiency of Astronomical Spectrographs," by Joseph Moore.

Wednesday Afternoon (at Stanford University)

"Discussion and Demonstrations of High Potential Electric Currents," by Harris J. Ryan.

⁴ See Taylor's address before the Physical Chemical Section of the American Chemical Society, New Orleans, April 1-3, 1915, and *Physical Review*, 6, 61 (1915).

Thursday Forenoon and Afternoon—Physics of the Air

"The Thunderstorm," by W. J. Humphreys.

"New Concepts in Aërology," by A. G. McAdie.

"The Application of Physical Principles to Problems Suggested by Oceanic Circulation and Temperatures," by George F. McEwen.

"Radiation and the Atmosphere," by C. G. Abbot.

"Solar Radiation and Terrestrial Magnetism," by L. A. Bauer.

"On the Origin and Maintenance of the Earth's Negative Charge," by W. F. G. Swann.

"The Natural Charges of the Elements," by Fernando Sanford.

Friday Forenoon and Afternoon

"Thermo-electric Properties of Alloys of Bismuth and Tin," by A. E. Caswell.

"On the Free Vibrations of a Lecher System IV." (By title.) By F. C. Blake and Charles Sheard.

"Resistance of a Spark Gap," by W. P. Boynton.

"On the Resolving Power of Photographic Plates," by Orin Tugman.

"Sensitive Moving-coil Galvanometers," by Frank Wenner and Ernest Weibel.

"An Experimental Verification of the Law of Variation of Mass with Velocity for Cathode Rays," by Lloyd T. Jones.

"The Oxide Resistance Thermometer," by S. L. Brown.

"New Form of Radiation Pyrometer," by S. L. Brown.

"Electromotive Forces in Isothermal Metallic Circuits," by Gilbert N. Lewis.

"A New Method of Determining the Amplitude of Sound Vibrations in Air with Demonstration," by E. P. Lewis.

"An Application of the Koch Registering Microphotometer for Measuring the Sharpness of Photographic Images," by Orin Tugman.

"Photographic Study of the Tone of the Violin," by D. C. Miller.

"The Variation of the Photoelectric Current with the Angle of Emission," by Willard Gardner.

"A Quantitative Determination of the Earth's Penetrating Radiation," by C. H. Kunsman.

"Ultra-violet Absorption Spectra," by R. L. Sebastian.

"The Ultra-violet Spectra of Krypton and Xenon," by E. P. Lewis.

"The Law of Cohesion in Mercury," by P. A. Ross.